2 a) The 42 Volt Li-Po Battery

CSSI.-IV Program Listing

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PROGRAM ADEM
" Lithium Polymer Battery Model "
" Technical Consultant: Steve Cochran Phone:(317) 579-3730 "
" Delphi Indianapolis Tech Center,IN "
" Program Consultant: Dr. Yilmaz Sahinkaya, Phone:(650) 574-0254 "
" SMA, Inc., San Jose, CA "
" Model Creation Date: March 31, 2000 "
                  " Units : Metric "
                  " System Parameters "
" General Parameters"
" TFIN = Simulation Time (sec) "
CONSTANT TFIN    = 60.0
" TSCELL = Cell Control Starting Time (Sec) "
CONSTANT TSCELL = 1.0
" Lithium Polymer Battery Parameters "
" Electric Analog Circuit Parameters "
" Control Parameters "
" IBBMOD = Type of Battery Current Input "
" IBBMOD = 0.0 Means IB is defined by IBBT (Cycling Test)"
" IBBMOD = 1.0 Means IB is defined by a Discharge Step Input "
" IBBMOD = 2.0 Means IB is defined by Discharge/Charge Step Inputs "
CONSTANT IBBMOD = 0.0
" IB    = Battery Current Command (Amperes(Amps) vs Time(sec)"
  " Cycling Test Current Command Table Function "
  TABLE IBBT, 1, 12,...
  0.0, 0.005, 18.0, 18.005, 50.0, 50.005, 52.0, 53.0, 56.0,...
  57.0, 59.005, 60.0,...
  0.0, -100.0, -100.0, 0.0, 0.0, 80.0, 80.0, 60.0, 60.0,...
  50.0, 50.0, 0.0
  " Discharge/Charge Test Current Command Table Function "
  TABLE IDACT, 1, 21,...
  0.0, 1.0, 2500.0, 2501.0, 2750.0, 2751.0, 8800.0, 8801.0, 8810.0,.
  8811.0, 8820.0, 8821.0, 8830.0, 8831.0, 8840.0, 8841.0, 8850.0,...
  8851.0, 8860.0, 8861.0, 10000.0,...
  0.0, -50.0, -50.0, 0.0, 0.0, 20.0, 20.0, 0.0, 0.0,...
  10.0, 10.0, 0.0, 0.0, 5.0, 5.0, 0.0, 0.0,...
  1.0, 1.0, 0.0, 0.0
CONSTANT IBPER42 = 60.0              $" Period (sec) "
CONSTANT IBBIN   = 0.0               $" Discharge Current Step (Amps) "
" Cycling Test Data for 1 Cycle of VC (Cell Voltage) "
" VCTEST = Cell Voltage ( Volt) vs Time (Sec) "
  TABLE VCTEST, 1, 16,...
  0.0, 5.0, 10.0, 15.0, 18.0, 19.0, 20.0, 25.0, 30.0, 50.0,...
  51.0, 52.0, 53.0, 55.0, 57.0, 60.0,...
  3.8, 3.75, 3.74, 3.72, 3.70, 3.95, 4.0, 4.025, 4.030, 4.050,...
  4.25, 4.20, 4.18, 4.24, 4.20, 4.22
" Discharge/Charge Test Data of VB (Battery voltage) "
" VBTEST = Battery Voltage (Volt) vs Time (Sec) "
  TABLE VBTEST, 1, 17,...
  0.0, 1.0, 1000.0, 2000.0,2250.0, 2500.0, 2501.0, 2750.0, 3000.0,..
  3750.0, 4000.0, 5000.0, 6000.0, 7000.0, 8000.0, 9000.0, 10000.0,..
  42.0, 40.6, 39.0, 37.4, 37.0, 33.0, 34.0, 34.2, 37.0,...
  38.0, 38.2, 39.2, 39.8, 40.5, 41.5, 42.0, 42.0
" Battery Storage Capacitance Parameters "
" VCMN  = Minimum Cell Voltage (Volt) "
CONSTANT VCMN  = 3.7
" VCMX  = Maximum Cell Voltage (Volt) "
CONSTANT VCMX  = 4.7
" CSBT  = Battery Storage Capacitance (F) vs Current (A) "
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TABLE CSBT, 1, 13,...
-200.0,-100.0,-75.0,-50.0,-25.0,-5.0, 0.0,...
 5.0, 25.0, 50.0, 75.0, 100.0, 200.0,...
 4.0E+5, 4.0E+5, 3.5E+5, 3.0E+5, 2.25E+5, 2.25E+5, 1.0E+5,...
 2.25E+5, 2.25E+5, 3.0E+5, 3.5E+5, 4.0E+5, 4.0E+5
TABLE CSBLT, 1, 13,...
-200.0,-100.0,-75.0,-50.0,-25.0,-5.0, 0.0,...
 5.0, 25.0, 50.0, 75.0, 100.0, 200.0,...
 4.5E+4, 4.5E+4, 2.5E+4, 3.0E+4, 3.0E+4, 3.0E+4, 3.0E+4,...
 3.0E+4, 3.0E+4, 3.0E+4, 3.0E+4, 3.0E+4, 3.0E+4
" VCON1 = Cell-1 Maximum Voltage (Volts) "
CONSTANT VCON1    = 4.2
" VCON2 = Cell-2 Maximum voltage (Volts) "
CONSTANT VCON2    = 4.2
" VCON3 = Cell-3 Maximum Voltage (Volts) "
CONSTANT VCON3    = 4.2
" VCON4 = Cell-4 Maximum Voltage (Volts) "
CONSTANT VCON4    = 4.2
" VCON5 = Cell-5 Maximum Voltage (Volts) "
CONSTANT VCON5    = 4.2
" VCON6 = Cell-6 Maximum Voltage (Volts) "
CONSTANT VCON6    = 4.2
" VCON7 = Cell-7 Maximum Voltage (Volts) "
CONSTANT VCON7    = 4.2
" VCON8 = Cell-8 Maximum Voltage (Volts) "
CONSTANT VCON8    = 4.2
" VCON9 = Cell-9 Maximum Voltage (Volts) "
CONSTANT VCON9    = 4.2
" VCON10= Cell-10 Maximum Voltage (Volts)"
CONSTANT VCON10   = 4.2
" RIB  = Battery Internal Resistance (Ohms) "
" RIB varies with TIB = Interior Battery Temperature "
" TIB  = Interior Battery Temperature (Deg C) "
" CFRBT= Temperature Correction Factor for TIB "
" Cell Resistance values at 25 Deg C (Ohms) "
CONSTANT RIC1I = 0.00250, RLC1I = 4.65E+3, RCON1I = 36.0    $" Cell-1
CONSTANT RIC2I = 0.00250, RLC2I = 4.65E+3, RCON2I = 36.0    $" Cell-2
CONSTANT RIC3I = 0.00250, RLC3I = 4.65E+3, RCON3I = 36.0    $" Cell-3
CONSTANT RIC4I = 0.00250, RLC4I = 4.65E+3, RCON4I = 36.0    $" Cell-4
CONSTANT RIC5I = 0.00250, RLC5I = 4.65E+3, RCON5I = 36.0    $" Cell-5
CONSTANT RIC6I = 0.00250, RLC6I = 4.65E+3, RCON6I = 36.0    $" Cell-6
CONSTANT RIC7I = 0.00250, RLC7I = 4.65E+3, RCON7I = 36.0    $" Cell-7
CONSTANT RIC8I = 0.00250, RLC8I = 4.65E+3, RCON8I = 36.0    $" Cell-8
CONSTANT RIC9I = 0.00250, RLC9I = 4.65E+3, RCON9I = 36.0    $" Cell-9
CONSTANT RIC10I= 0.00250, RLC10I= 4.65E+3, RCON10I= 36.0    $" Cell-1
TABLE CFRBT, 1, 7,...
-45.0, -29.0, -18.0  0.0, 25.0, 52.0, 75.0,...
 3.0, 3.0, 2.0, 1.2, 1.0, 1.0, 1.0
" Initial Values of State Variables "
CONSTANT AHBZ = 35.0        $" Initial Battery AH Capacity "
" AHBR  = Battery Ampere-Hour Rating "
CONSTANT AHBR = 35.0
" Cell Open-Circuit Voltages (Volts) "
CONSTANT VOCC1Z = 4.2, VOCC2Z = 4.2, VOCC3Z = 4.2, VOCC4Z = 4.2,...
CONSTANT VOCC5Z = 4.2, VOCC6Z = 4.2, VOCC7Z = 4.2, VOCC8Z = 4.2,...
CONSTANT VOCC9Z = 4.2, VOCC10Z = 4.2
" CELCON = Cell Controller Logic Macro "
" CELCON Definition "
  MACRO PMACRO CELCON, P
  IF(P(2).GE.P(3))    THEN
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        P(1)    =  1.0
    ELSE
        P(1)    =  0.0
    ENDIF
    MACRO END
" CELCAP = Cell Capacitance Selection Logic "
" CELCAP Definition "
    MACRO PMACRO CELCAP, P
    IF(P(3).LE.P(2).AND.P(2).LE.P(4))      THEN
       P(1) = P(5)
    ELSEIF(P(2).LT.P(3).OR.P(2).GT.P(4))   THEN
       P(1) = P(6)
    ENDIF
    MACRO END
" CELCOM = Cell Computation Macro "
" CELCOM Definition "
    MACRO MACRO CELCOM, P
    P(2)    = P(5)-P(6)-P(7)
    P(3)    = (1.0/P(8))*P(2)
    P(1)    = INTEG(P(3), P(9))
    P(4)    = P(10)*P(5)**2 + P(11)*P(6)**2 + P(12)*P(7)**2
    MACRO END
" Thermal Model Parameters "
" MPOLY  = Electrolyte Mass (kg)"
" CPPOLY = Electrolyte Specific Heat (Joules/kg-deg C) "
CONSTANT MPOLY  = 1.9 , CPPOLY  = 1590.0
" MCOP   = Copper Mesh Mass (kg)"
" CPCOP  = Copper Mesh Specific Heat  (Joules/kg-deg C)"
CONSTANT MCOP   = 1.37, CPCOP   = 381.0
" MALUM  = Aluminum Mesh Mass (kg) "
" CPALUM = Aluminum Mesh Specific Heat (Joules/kg-deg C) "
CONSTANT MALUM  = 0.150, CPALUM = 870.0
" MSTL   = Steel Mass (kg) "
" CPSTL  = Steel Specific Heat (Joules/kg-deg C) "
CONSTANT MSTL   = 0.140, CPSTL  = 477.0
" Battery Plastic Can Parameters "
CONSTANT THKB   = 3.0          $" Thickness(mm) "
CONSTANT KSB    = 1.903E-4     $" Conductance Coefficient(Watts/mm-deg C
CONSTANT ASB    = 8.48E+5      $" Surface Area (mm**2) "
" MSB14 = Surface Mass (kg) "
CONSTANT  MSB   = 10.0
" CPS   = Surface Specific Heat (Joules/kg-deg C) "
CONSTANT CPSB   = 1590.0
" KOB14 = Convective Heat Transfer Coefficient(Watts/mm**2-Deg C)"
CONSTANT KOB    = 156.45E-6
" Initial Conditions on State Variables "
CONSTANT TIBZ   = 25.0,  TSBZ = 25.0  $" Deg C "
" TOB14 = Outside Air Temperature "
CONSTANT TOB    = 25.0                 $" Deg C "
            " Initial Region Computations "
INITIAL
" Thermal model Computed Parameters "
" CTHIB = Battery Interior Thermal Capacitance (Watt-Sec/deg C) "
CTHIB   = MPOLY*CPPOLY+MCOP*CPCOP+MALUM*CPALUM+MSTL*CPSTL
" RSB   = Surface Conductive Heat Transfer Resistance(deg C/Watts)"
RSB     = THKB/(KSB*ASB)
" CTHSB = Battery Surface Thermal Capacitance (Watt-Sec/deg C) "
CTHSB   = MSB*CPSB
" ROB   = Surface Convective Heat Transfer Coefficient(deg C/Watts) "
ROB     = 1.0/(KOB*ASB)
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END INITIAL
                    " Dynamic and Derivative Region Computations "
 DYNAMIC
  DERIVATIVE EQS
                    " Simulation Controls "
  ALGORITHM ISTART = 5, IRUN = 5
  CINTERVAL CI     = 0.5
  NSTEPS    NST    = 500
  MINTERVAL HMINT = 1.0E-20
  " State Equations for the electric analog circuit model "
  " Positive Current = Charge, Negative Current = Discharge "
  " CFRC = Resistance Correction Factor "
  CFRC   = CFRBT(TIB)
  " State Equations "
  IBBTAB = IBBT(AMOD(T,IBPER42))
  IBBDIS = IBBIN*STEP(TSCELL,T)
  IBBDAC = IDACT(T)
  PROCEDURAL(IBC10 = IBBTAB, IBBDIS, IBBDAC, IBBMOD)
    IF(T.LT.TSCELL)    THEN
      IBC10    = 0.0
    ELSEIF(T.GE.TSCELL.AND.IBBMOD.LT.0.5)   THEN
      IBC10    = IBBTAB
    ELSEIF(T.GE.TSCELL.AND.0.5.LE.IBBMOD.AND.IBBMOD.LE.1.5)   THEN
      IBC10    = IBBDIS
    ELSEIF(T.GE.TSCELL.AND.IBBMOD.GT.1.5) THEN
      IBC10    = IBBDAC
    ENDIF
  END
  " Compute Battery Storage Capacitance "
  CSB     = CSBT(IBC10)
  CSBL    = CSBLT(IBC10)
  " Cell-10 "
  SWC10   = CELCON(VC10,VCON10)
  VOCC10,ICC10,VOCC10S,PWLC10 = CELCOM(IBC10,ILC10,ICON10,CSC10,...
                                       VOCC10Z,RIC10,RLC10,RCON10)
  CSC10   = CELCAP(VC10,VCMN,VCMX,CSB,CSBL)
  RIC10   = CFRC*RIC10I
  RLC10   = CFRC*RLC10I
  ILC10   = (VOCC10/RLC10)
  RCON10  = CFRC*RCON10I
  ICON10  = (SWC10*VOCC10)/RCON10
  VC10    = VOCC10+ RIC10*IBC10
  VB10    = VC10+VB9
  " Cell-9 "
  IBC9    = ICC10
  SWC9    = CELCON(VC9,VCON9)
  VOCC9,ICC9,VOCC9S,PWLC9 = CELCOM(IBC9,ILC9,ICON9,CSC9,...
                                   VOCC9Z,RIC9,RLC9,RCON9)
  CSC9    = CELCAP(VC9,VCMN,VCMX,CSB,CSBL)
  RIC9    = CFRC*RIC9I
  RLC9    = CFRC*RLC9I
  ILC9    = (VOCC9/RLC9)
  RCON9   = CFRC*RCON9I
  ICON9   = (SWC9*VOCC9)/RCON9
  VC9     = VOCC9+ RIC9*IBC9
  VB9     = VC9+VB8
  " Cell-8 "
  IBC8    = ICC9
  SWC8    = CELCON(VC8,VCON8)
  VOCC8,ICC8,VOCC8S,PWLC8 = CELCOM(IBC8,ILC8,ICON8,CSC8,...
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                                                VOCC8Z,RIC8,RLC8,RCON8)
CSC8    = CELCAP(VC8,VCMN,VCMX,CSB,CSBL)
RIC8    = CFRC*RIC8I
RLC8    = CFRC*RLC8I
ILC8    = (VOCC8/RLC8)
RCON8   = CFRC*RCON8I
ICON8   = (SWC8*VOCC8)/RCON8
VC8     = VOCC8+ RIC8*IBC8
VB8     = VC8+VB7
" Cell-7 "
IBC7    = ICC8
SWC7    = CELCON(VC7,VCON7)
VOCC7,ICC7,VOCC7S,PWLC7 = CELCOM(IBC7,ILC7,ICON7,CSC7,...
                                                VOCC7Z,RIC7,RLC7,RCON7)
CSC7    = CELCAP(VC7,VCMN,VCMX,CSB,CSBL)
RIC7    = CFRC*RIC7I
RLC7    = CFRC*RLC7I
ILC7    = (VOCC7/RLC7)
RCON7   = CFRC*RCON7I
ICON7   = (SWC7*VOCC7)/RCON7
VC7     = VOCC7+RIC7*IBC7
VB7     = VC7+VB6
" Cell-6 "
IBC6    = ICC7
SWC6    = CELCON(VC6,VCON6)
VOCC6,ICC6,VOCC6S,PWLC6 = CELCOM(IBC6,ILC6,ICON6,CSC6,...
                                                VOCC6Z,RIC6,RLC6,RCON6)
CSC6    = CELCAP(VC6,VCMN,VCMX,CSB,CSBL)
RIC6    = CFRC*RIC6I
RLC6    = CFRC*RLC6I
ILC6    = (VOCC6/RLC6)
RCON6   = CFRC*RCON6I
ICON6   = (SWC6*VOCC6)/RCON6
VC6     = VOCC6+ RIC6*IBC6
VB6     = VC6+ VB5
" Cell-5 "
IBC5    = ICC6
SWC5    = CELCON(VC5,VCON5)
VOCC5,ICC5,VOCC5S,PWLC5 = CELCOM(IBC5,ILC5,ICON5,CSC5,...
                                                VOCC5Z,RIC5,RLC5,RCON5)
CSC5    = CELCAP(VC5,VCMN,VCMX,CSB,CSBL)
RIC5    = CFRC*RIC5I
RLC5    = CFRC*RLC5I
ILC5    = (VOCC5/RLC5)
RCON5   = CFRC*RCON5I
ICON5   = (SWC5*VOCC5)/RCON5
VC5     = VOCC5+RIC5*IBC5
VB5     = VC5+ VB4
" Cell-4 "
IBC4    = ICC5
SWC4    = CELCON(VC4,VCON4)
VOCC4,ICC4,VOCC4S,PWLC4 = CELCOM(IBC4,ILC4,ICON4,CSC4,...
                                                VOCC4Z,RIC4,RLC4,RCON4)
CSC4    = CELCAP(VC4,VCMN,VCMX,CSB,CSBL)
RIC4    = CFRC*RIC4I
RLC4    = CFRC*RLC4I
ILC4    = (VOCC4/RLC4)
RCON4   = CFRC*RCON4I
ICON4   = (SWC4*VOCC4)/RCON4
VC4     = VOCC4+RIC4*IBC4
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VB4     = VC4+ VB3
" Cell-3 "
IBC3    = ICC4
SWC3    = CELCON(VC3,VCON3)
VOCC3,ICC3,VOCC3S,PWLC3 = CELCOM(IBC3,ILC3,ICON3,CSC3,...
                                 VOCC3Z,RIC3,RLC3,RCON3)
CSC3    = CELCAP(VC3,VCMN,VCMX,CSB,CSBL)
RIC3    = CFRC*RIC3I
RLC3    = CFRC*RLC3I
ILC3    = (VOCC3/RLC3)
RCON3   = CFRC*RCON3I
ICON3   = (SWC3*VOCC3)/RCON3
VC3     = VOCC3 + RIC3*IBC3
VB3     = VC3 + VB2
" Cell-2 State Equations "
IBC2    = ICC3
SWC2    = CELCON(VC2,VCON2)
VOCC2,ICC2,VOCC2S,PWLC2 = CELCOM(IBC2,ILC2,ICON2,CSC2,...
                                 VOCC2Z,RIC2,RLC2,RCON2)
CSC2    = CELCAP(VC2,VCMN,VCMX,CSB,CSBL)
RIC2    = CFRC*RIC2I
RLC2    = CFRC*RLC2I
ILC2    = (VOCC2/RLC2)
RCON2   = CFRC*RCON2I
ICON2   = (SWC2*VOCC2)/RCON2
VC2     = VOCC2+ RIC2*IBC2
VB2     = VC2+VB1
" Cell-1 State Equations "
IBC1    = ICC2
SWC1    = CELCON(VC1,VCON1)
VOCC1,ICC1,VOCC1S,PWLC1 = CELCOM(IBC1,ILC1,ICON1,CSC1,...
                                 VOCC1Z,RIC1,RLC1,RCON1)
CSC1    = CELCAP(VC1,VCMN,VCMX,CSB,CSBL)
RIC1    = CFRC*RIC1I
RLC1    = CFRC*RLC1I
ILC1    = (VOCC1/RLC1)
RCON1   = CFRC*RCON1I
ICON1   = (SWC1*VOCC1)/RCON1
VC1     = VOCC1+ RIC1*IBC1
VB1 = VC1
" AHB   = Net Battery Ampere-Hour Capacity (AH) "
AHBS    = (1.0/3600.0)*ICC10
AHB     = INTEG(AHBS,AHBZ)
" State Of Charge (SOC) "
SOC     = (AHB/AHBR)
" 1 Cell Voltage Test Data "
VCTD    = VCTEST(T)
" Battery Voltage Test Data "
VBTD    = VBTEST(T)
" Power Computations "
" PWBC  = Power at the Battery Output (Watts) "
PWBC    = VB10*IBC10
" State Equations for the Thermal Model "
" TIBS  = Rate of Interior Battery Temperature (Deg C/sec)"
" TIB   = Interior Battery Temperature (Deg C)"
" CTHIB = Battery Interior Capacitance (Watt-Sec / Deg C) "
" HINB  = Input Heating Power (Watts) "
HINB = PWLC1+PWLC2+PWLC3+PWLC4+PWLC5+PWLC6+PWLC7+PWLC8+PWLC9+PWL(
" HSB   = Interor-Surface Conduction Heat Transfer (Watts) "
" TSB   = Battery Surface Temperature (deg C) "
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  " RSB    = Interior-Surface Conduction H-T Coefficient(deg C/Watts)
  HSB      = (TIB-TSB)/RSB
  TIBS     = (1.0/CTHIB)*(HINB-HSB)
  TIB      = INTEG(TIBS,TIBZ)
  " TSBS   = Rate of Battery Surface Temperature (deg C / sec) "
  " TSB    = Battery Surface Temperature (deg C) "
  " CTHS   = Battery Surface Thermal Capacitance (Watt-Sec/deg C ) "
  " HOB    = Surface-to-Outside Convective Heat Transfer (Watts) "
  " TOB    = Outside Air Temperature (deg C ) "
  " ROB    = Surface-to-Outside Convective H-T Coefficient(deg C/Watt
  HOB      = (TSB-TOB)/ROB
  TSBS     = (1.0/CTHSB)*(HSB-HOB)
  TSB      = INTEG(TSBS,TSBZ)
   END DERIVATIVE
 TERMT(T.GE.TFIN)
 END DYNAMIC
                  " Terminal Region Computations "
 TERMINAL
 END TERMINAL

END PROGRAM
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